Intraband emission of GaN quantum dots at λ =1.5 μm via resonant Raman scattering

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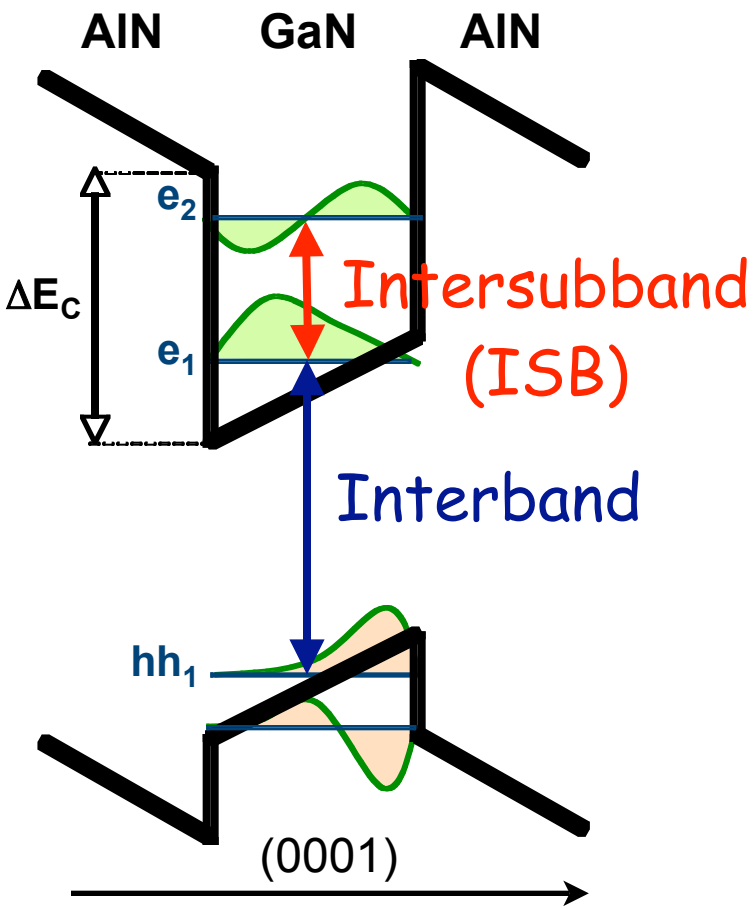
Outline

- Intraband properties of GaN/AlN quantum dots (QD)
- Intraband emission at telecom wavelengths
- Pump-probe measurements of intraband relaxation
- QD intraband absorption saturation
- Conclusions and prospects

Nitride intersubband transitions



Large CB offset:
ΔE_C ~1.75 eV GaN/AlN

Direct gap materials
Remote lateral valleys (>2eV)

ISB tunable at 1.3 - 1.55 μm

Electron effective mass (0.2 m_0)
3 times that of GaAs
Ultrathin layers (1-1.5 nm)

Huge internal fields (wurtzite)

Ultrafast ISB relaxation via electron scattering by LO-phonons (150-400 fs)

Nitride ISB devices at 1.3 - 1.55 μm

All-optical gates

Iizuka et al., APL 77, 648 (2000), JAP 99, 093107 (2006)

Photovoltaic QWIPs

Hofstetter et al. APL 88, 121112 (2006), Giorgetta et al. Electron. Lett. 43, 185 (2007)

Photoconductive QDIPs

Doyennette et al., Electron. Lett. 41, 1077 (2005); Vardi et al., APL 88, 143101, (2006)

Electro-optical modulators: QW depletion, electron tunneling, ...

Baumann et al., APL 89, 101121 (2006), Nevou et al., APL (2007)

Non-linear SHG devices

Nevou et al., APL 89, 151101 (2006)

Low-loss waveguides

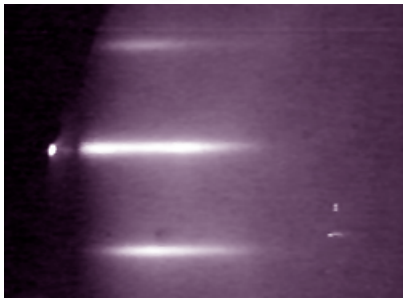
Lupu et al., IEEE PTL (2007)

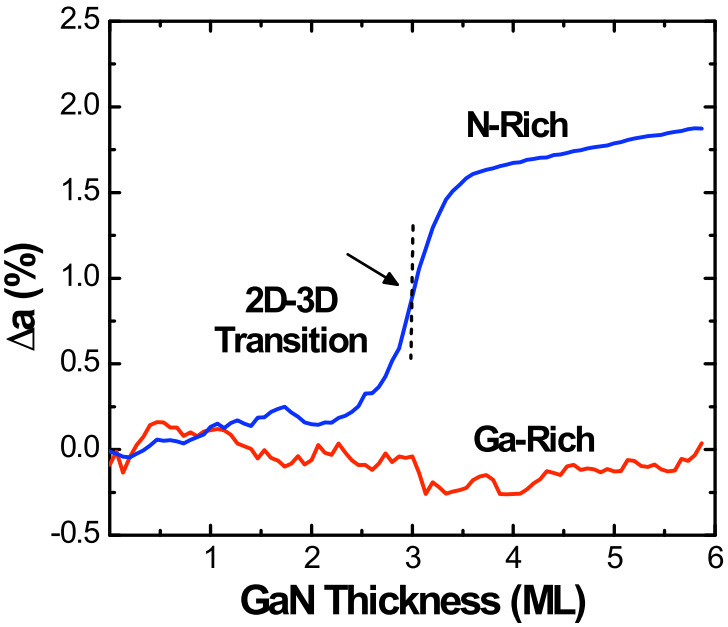
ISB light emission but no laser so far

Nevou et al., Electron. Lett. 42, 1308 (2006); APL 90, 121106 (2007)

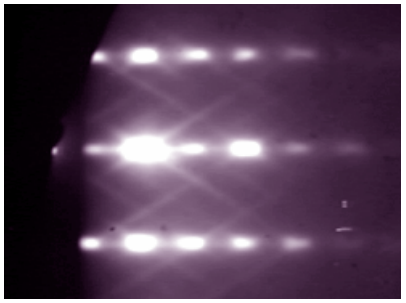
Nitride quantum dots grown by PA-MBE

Ga rich:
2D growth

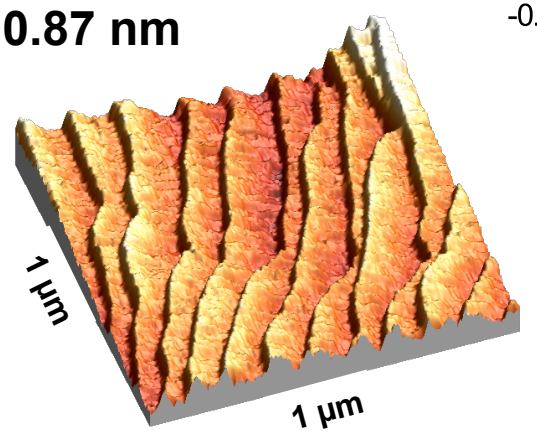




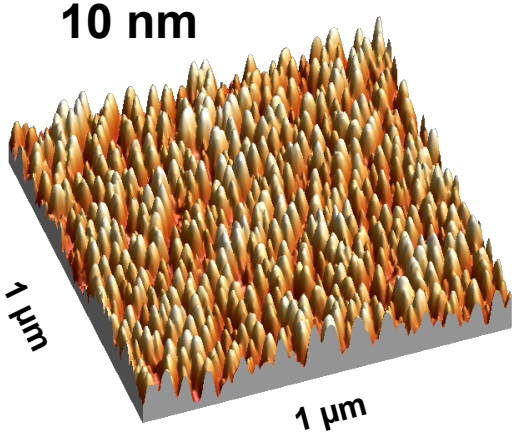
N rich: SK mode



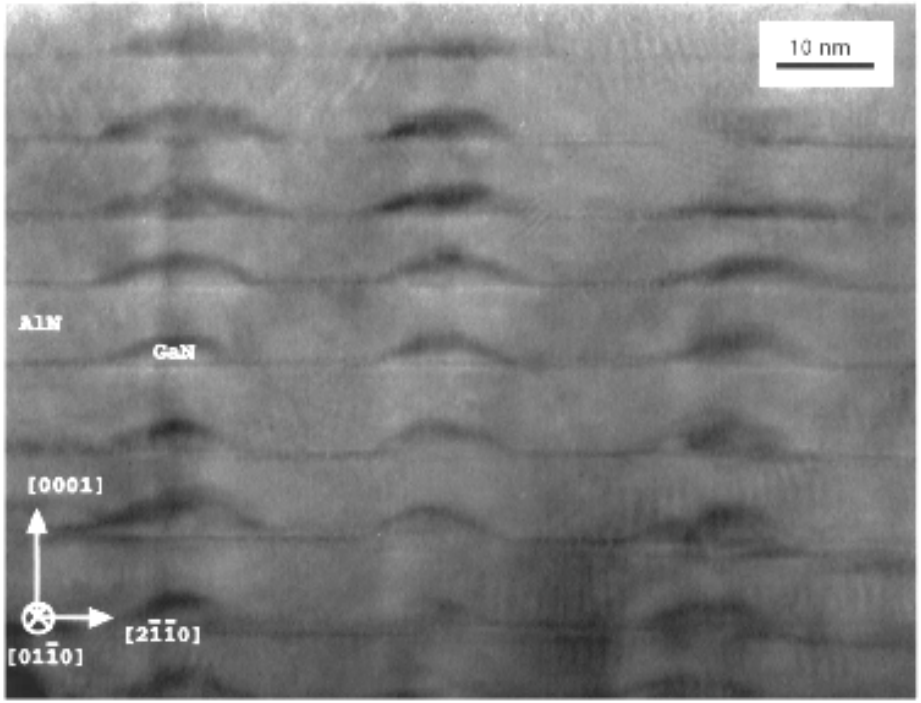
0.87 nm

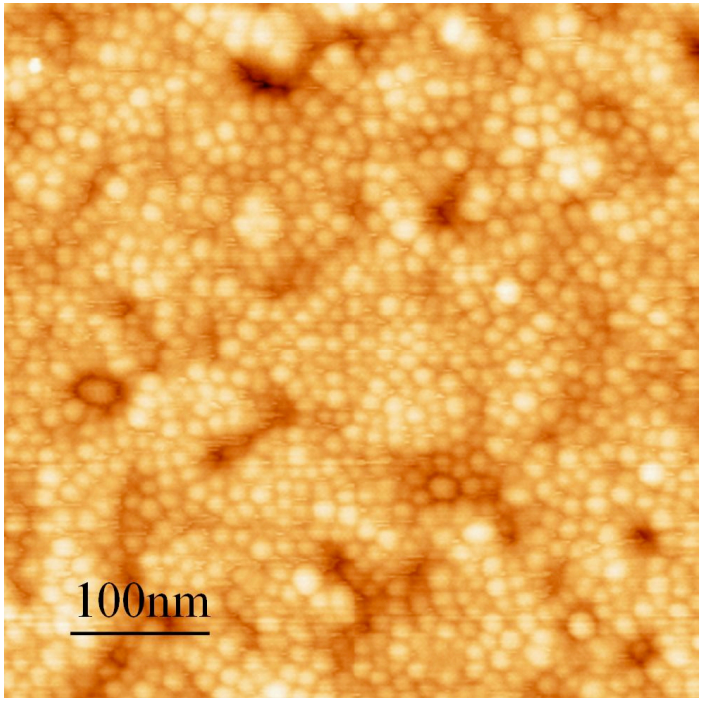


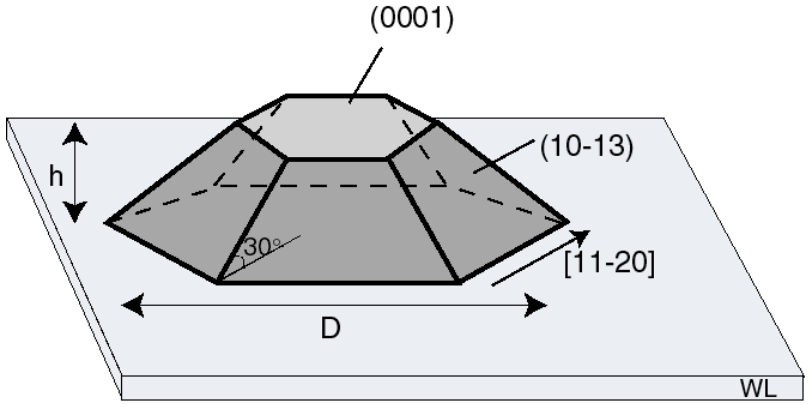
10 nm



Self-organized GaN/AlN quantum dots

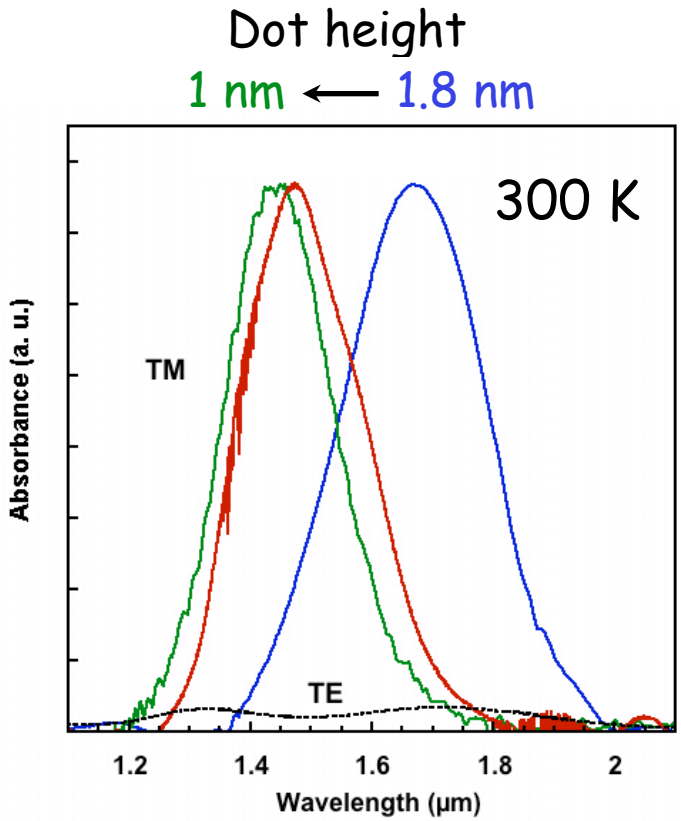


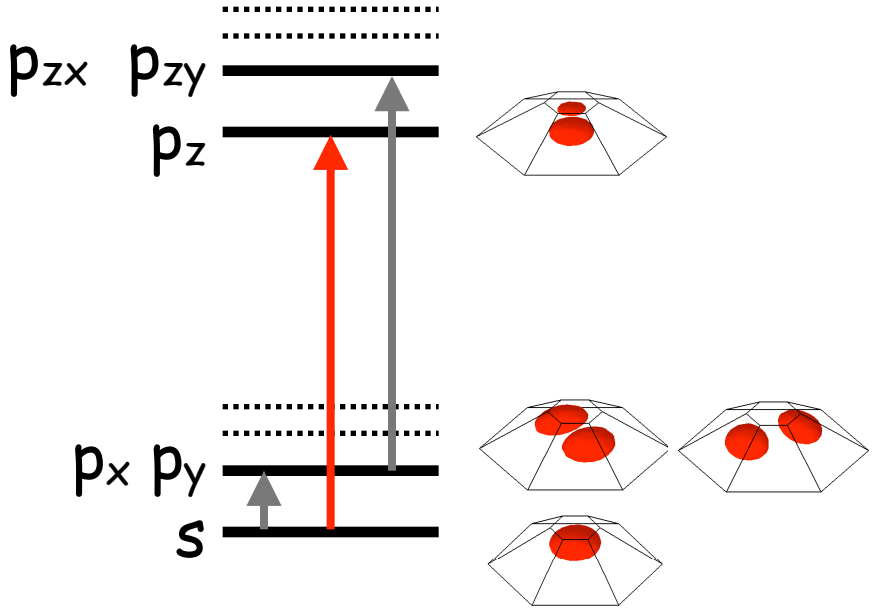




Widmann et al. JAP 83, 7618 (1998); F. Guillot et al., JAP 100, 044326 (2006)

Intraband spectroscopy



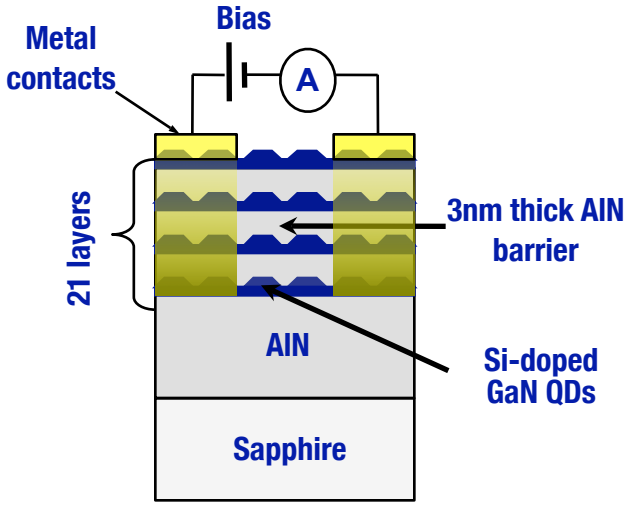


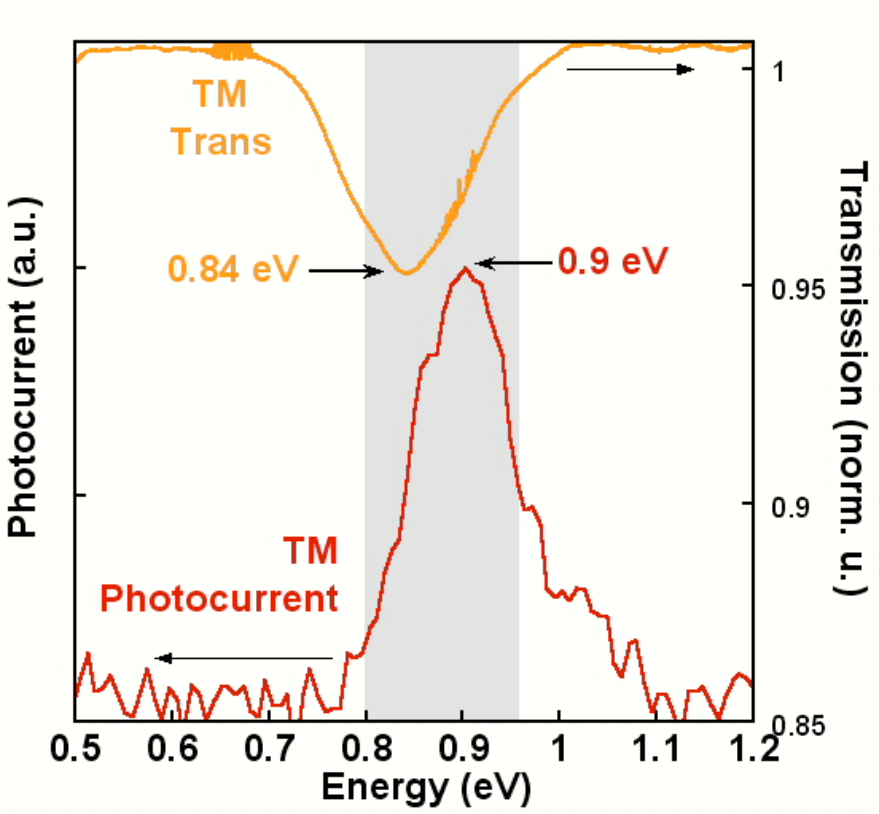
Andreev et al., PRB 62, 15851 (2000)

- 20 periods of Si-doped GaN QDs with 3 nm thick AlN barriers on AlN/c-sapphire template.
- Intraband absorption p-polarized, FWHM 100-150 meV

M. Tchernycheva et al., APL 87, 101912 (2005); F. Guillot et al., JAP 100, 044326 (2006)

Quantum dot intraband photodetector





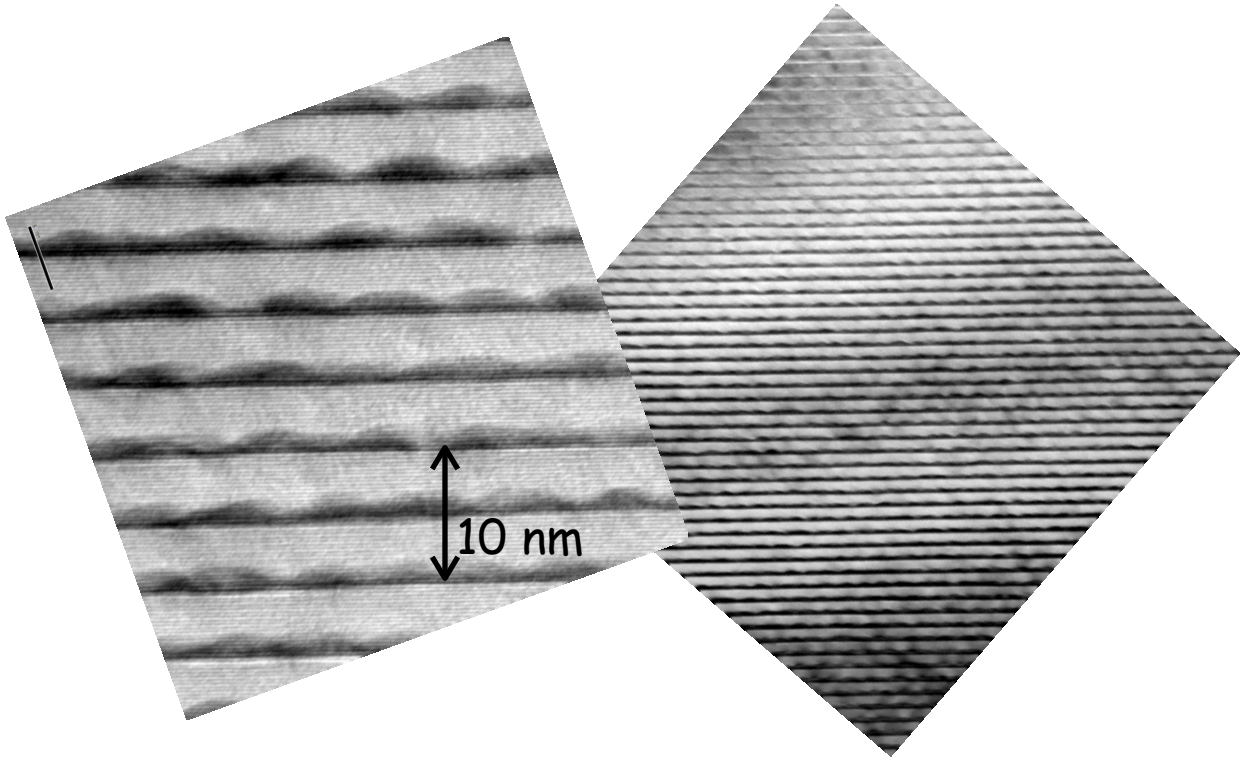
- s-pz intraband absorption + in-plane transport in the WL
- 300 K responsivity 12 mA/W at λ=1.4 μm

L. Doyennette et al., Electron. Lett., 41, 1077, (2005); A. Vardi et al., Appl. Phys. Lett., 88, 143101, (2006)

Quantum dot superlattice sample

200 period QD SL 4 ML GaN/3 nm AlN PAMBE
1 µm AlN MOCVD
c-sapphire substrate

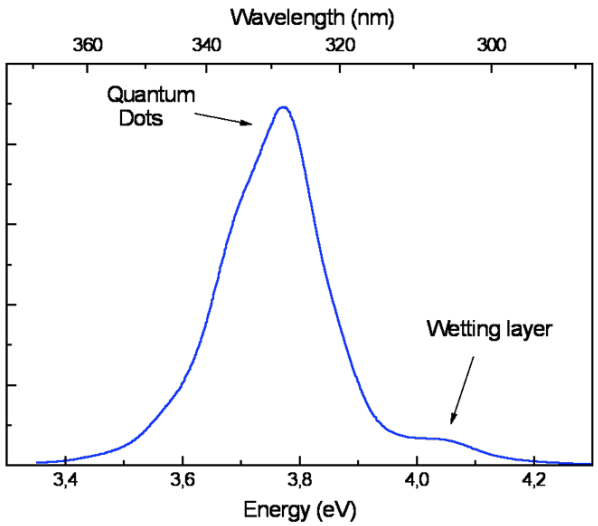
Si doping of GaN layer:
1×10^{20} cm^{-3}



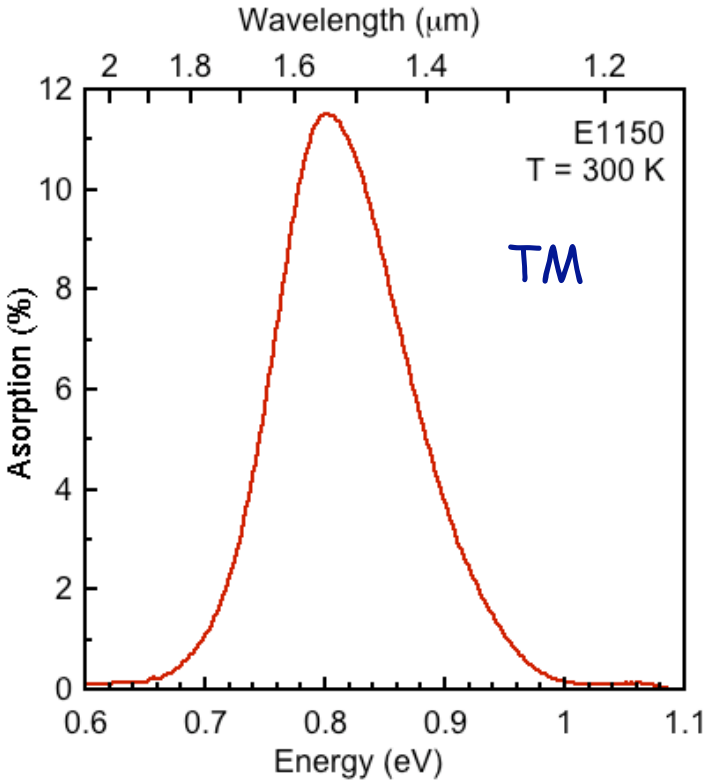
- QD height 1.7 nm including 0.5 nm WL
- QD diameter 6±1 nm
- Density: 1.2×10^{12} cm^{-2}

PA-MBE growth N-rich T= 700°C, E. Monroy et al. CEA Grenoble

Optical spectroscopy



Photoluminescence 300K

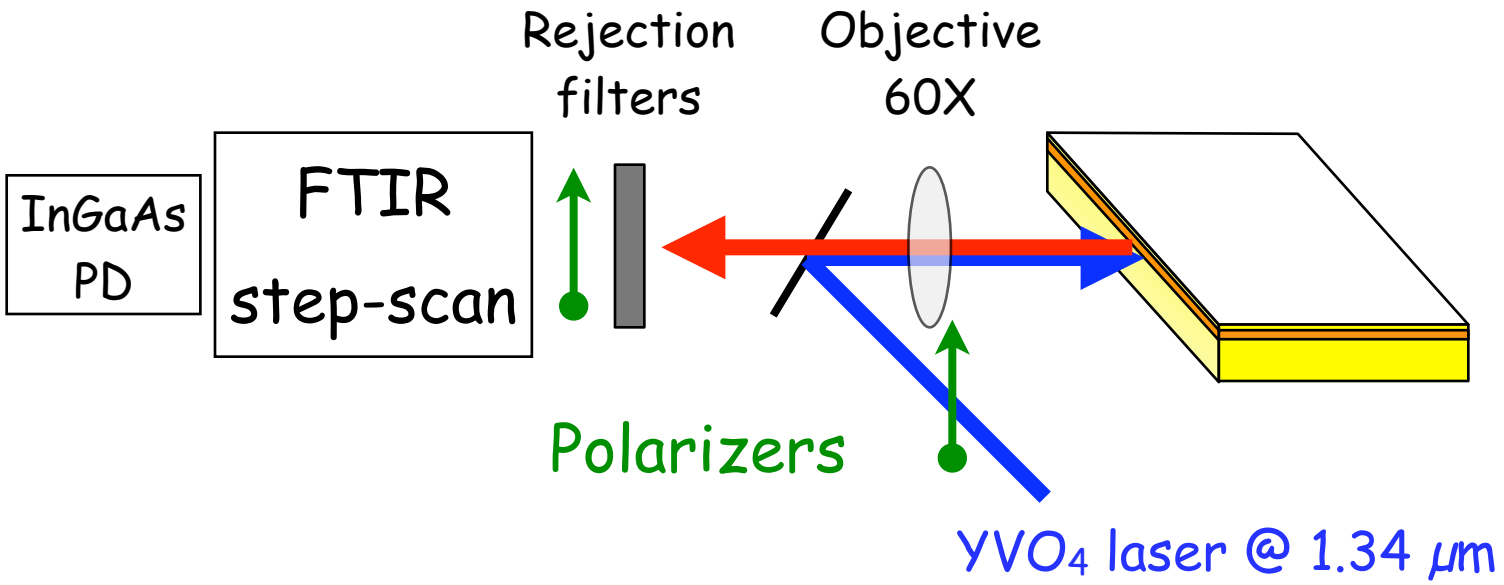


Absorption s-p_z 300K

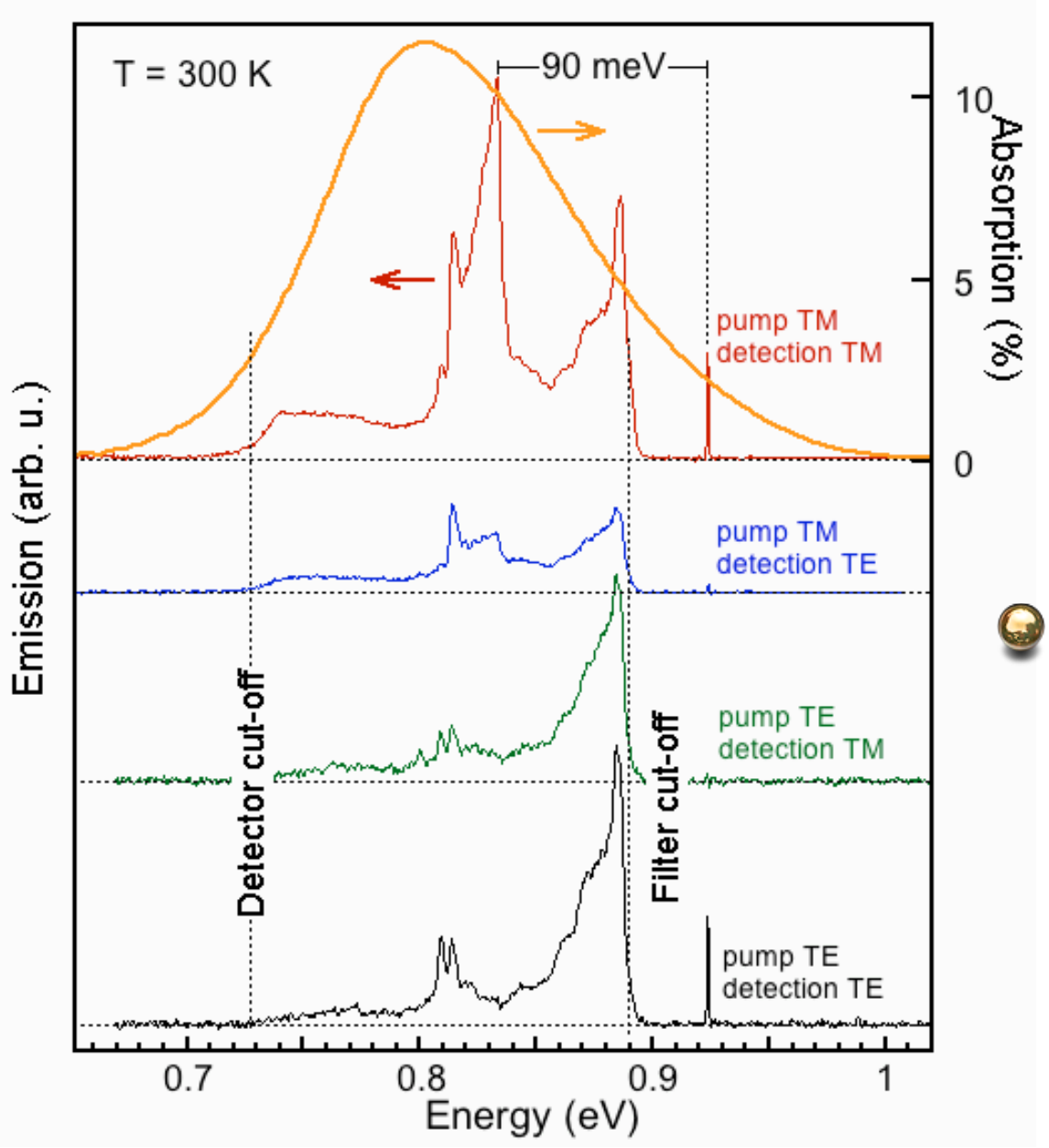
- s-p_z intraband absorption 11.5% at Brewster's angle
- Rather small broadening : FWHM 120 meV

PA-MBE growth E. Monroy et al. CEA Grenoble

Emission set-up

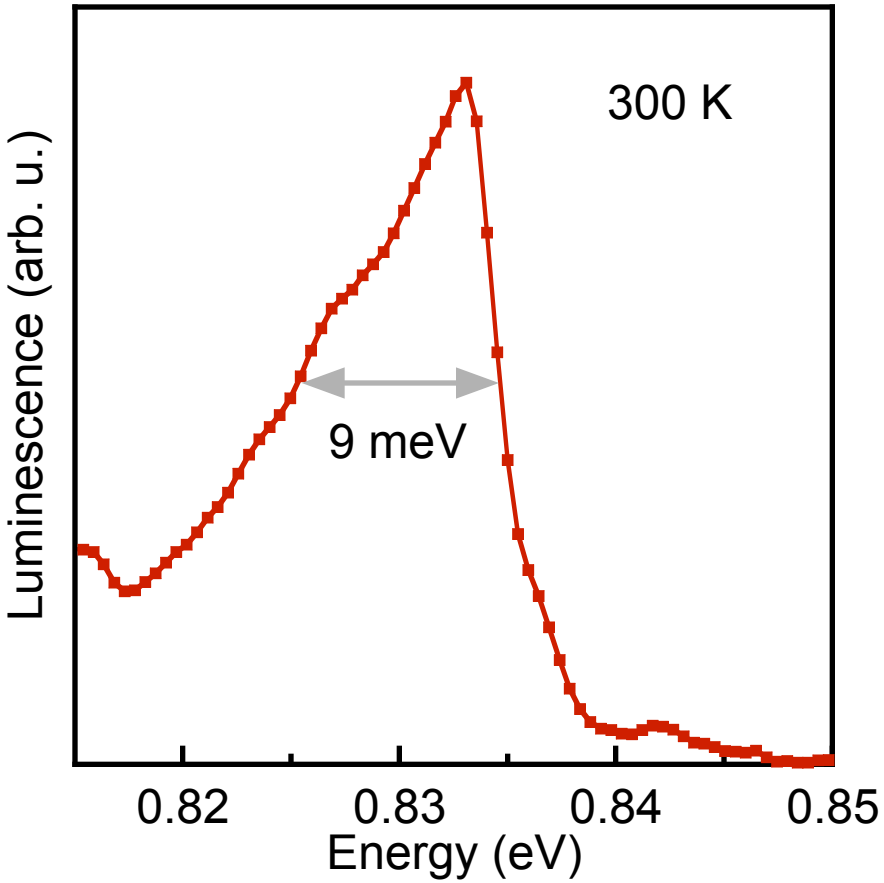


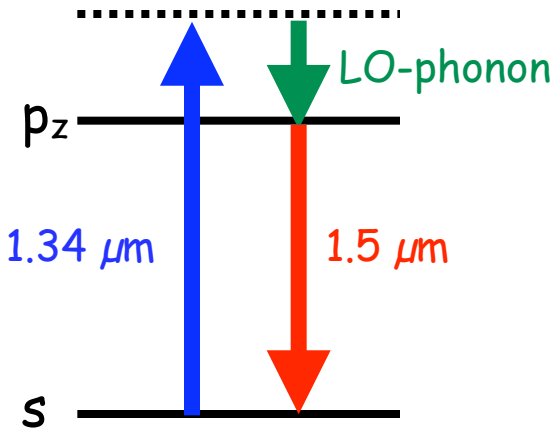
Quantum dot intraband emission



- P-polarized emission at 1.48 μm only under p-polarized excitation at 1.34 μm.

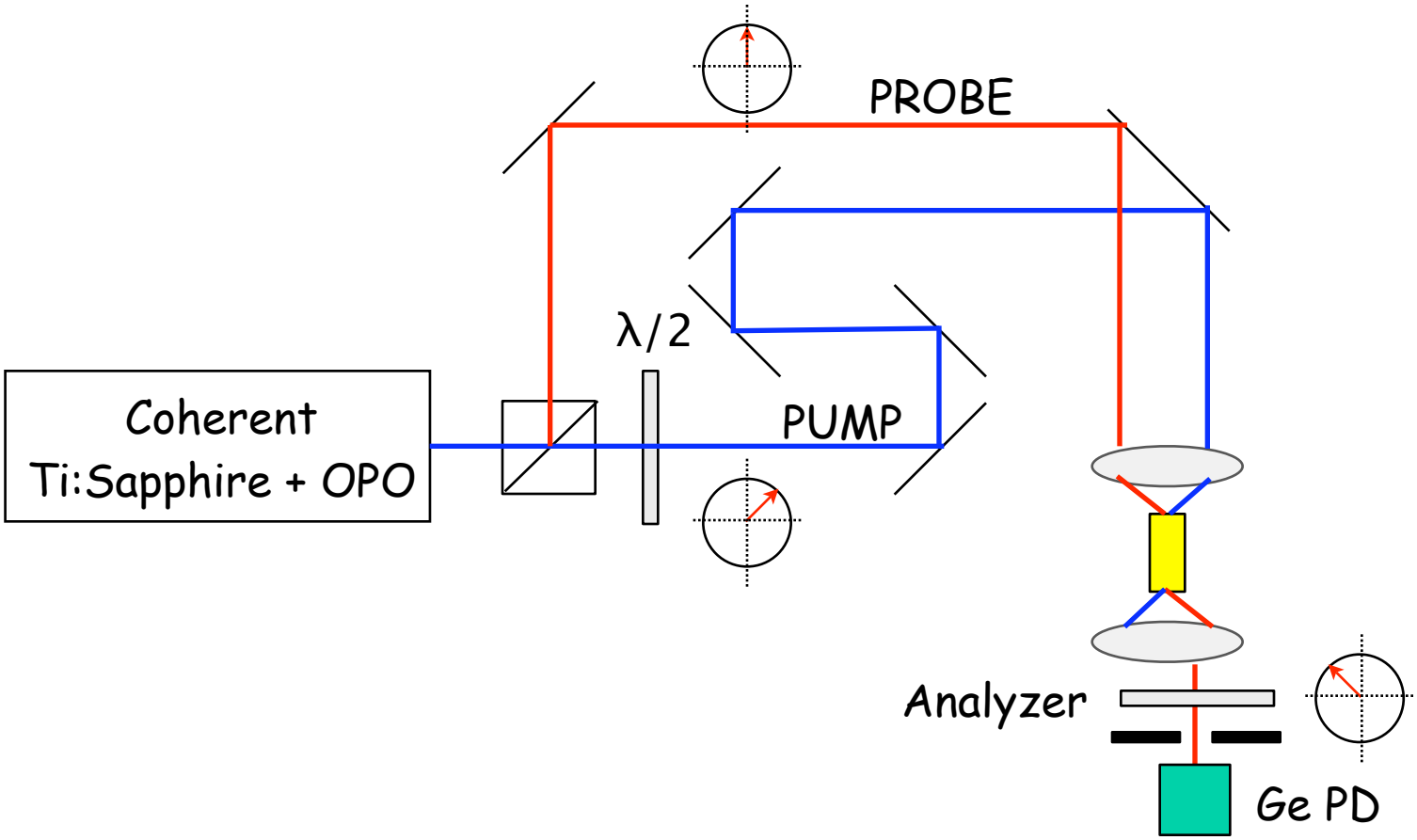
Quantum dot intraband emission





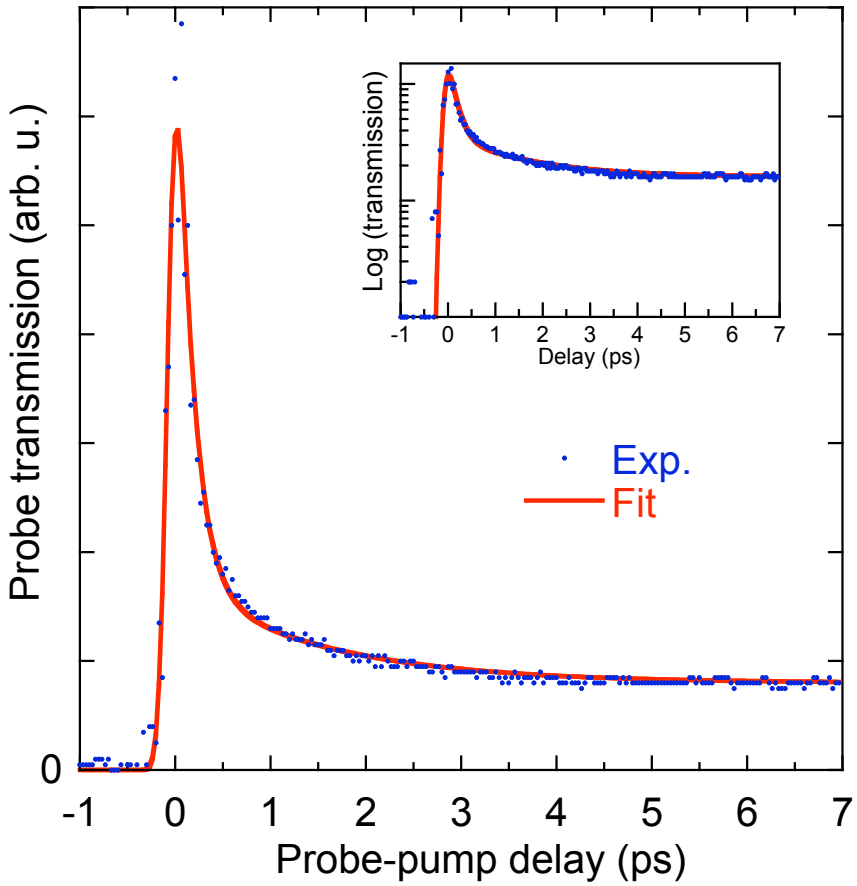
- Emission ascribed to p_z-s transition.
- p_z population via scattering by zero-momentum GaN LO-phonon
- Intraband linewidth <9 meV (QW ISB linewidth 40 meV)

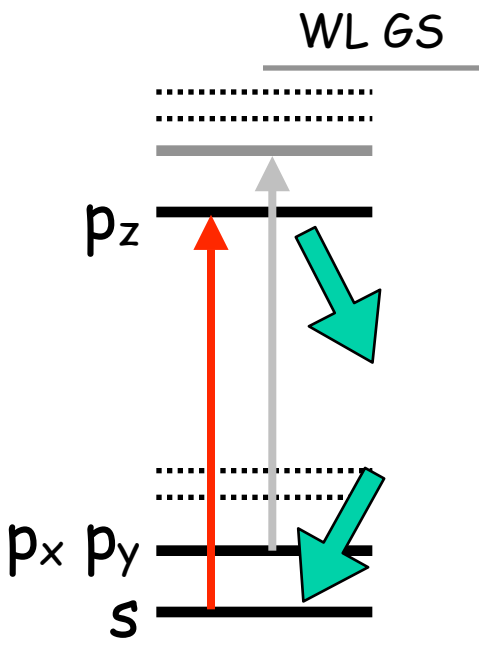
Femtosecond pump-probe set-up



- Pump and probe at 1.55 μm , FWHM 150 fs, Δλ=25 nm
- Multi-pass waveguide with 2 internal reflections.

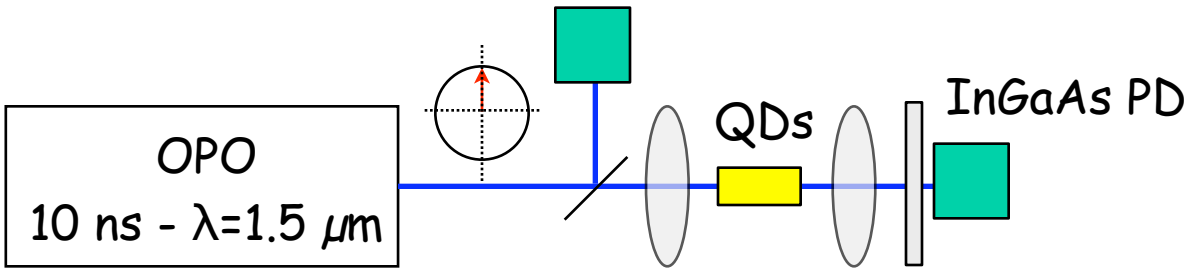
Femtosecond pump-probe spectroscopy





- Multi- exponential decay: τ_1 = 165 fs, τ_2 = 1.5 ps
- Intraband absorption recovery time (T_1) comparable for QDs and QWs.

Intraband absorption saturation



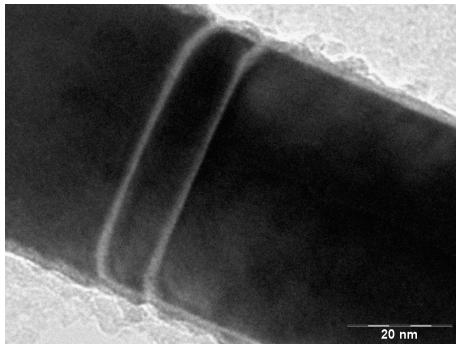
- Multi-pass waveguide with 2 internal reflections.
- Saturation intensity of intraband absorption I_s~50 MW.cm^{-2}
- Saturation intensity is ten times smaller for QDs than for QWs.

$$I_s \propto h\nu/(fT_1T_2)$$

- Another indication that T_2 is much longer for QDs.
- Homogeneous broadening for QD ≤ 5 meV (FWHM)

Conclusions

- First demonstration of intraband luminescence from GaN/AlN quantum dots:
  - Record-short ISB wavelength (1.5 μm) and room temperature
  - Population inversion achievable but broad spectral excitation likely to be required for net gain at 1.5 μm wavelength.
- QD intraband saturable absorbers of great interest for all-optical switching applications.
- Other prospects: probing the intraband absorption of a single GaN QD at 1.5 μm



- This work was part of the NitWAve project (European FP6 IST program #004170) http://pages.ief.u-psud.fr/nitwave